

For Publisher's use

# BILINEAR R-PARITY VIOLATING SUSY: SOLVING THE SOLAR AND ATMOSPHERIC NEUTRINO PROBLEMS

M. HIRSCH, W. POROD AND J. W. F. VALLE

*Instituto de Física Corpuscular – C.S.I.C., Departamento de Física Teòrica, Universitat de València, Edificio Institutos de Paterna, Apartado de Correos 22085, 46071 València*

M. A. DÍAZ

*Fac. de Física, Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Santiago, Chile*

J. C. ROMÃO

*Depto. de Física, Inst. Superior Técnico, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal*

Bilinear R-parity violation is a simple extension of the MSSM allowing for Majorana neutrino masses. One of the three neutrinos picks up mass by mixing with the neutralinos of the MSSM, while the other two neutrinos gain mass from 1-loop corrections. Once 1-loop corrections are carefully taken into account the model is able to explain solar and atmospheric neutrino data for specific though simple choices of the R-parity violating parameters.

## 1 Introduction

Atmospheric neutrino data so far provides the most compelling evidence for non-zero neutrino masses<sup>1</sup>, indicating large mixing among neutrino flavours and a typical  $\Delta m_{ij}^2$  of the order of  $\Delta m_{ij}^2 \sim (\text{few}) \cdot 10^{-3} \text{ eV}^2$ . On the other hand, despite new high quality data, the long standing solar neutrino problem still allows both large and small mixing angle values for neutrinos<sup>2</sup> and  $\Delta m^2 \sim \mathcal{O}(10^{-5}) \text{ eV}^2$  or  $\Delta m^2 \sim \mathcal{O}(10^{-7}) \text{ eV}^2$ <sup>2</sup> (SMA and LMA or LOW solutions of the solar neutrino problem, respectively).

Many attempts to explain neutrino masses can be found in the literature<sup>3</sup>. Here we summarize the work of<sup>4</sup>. It is based on a simple bilinear R-parity violating (BRPV) extension of the MSSM. This model, despite being minimalistic can explain atmospheric and solar neutrino data for specific ranges of model parameters. Its attractiveness lies in the fact that these parameter choices necessary to solve the neutrino problems give at the same time definite predictions for accelerator physics.<sup>5</sup>

## 2 Bilinear R-parity violating SUSY

In the simplest extension of the MSSM including R-parity violation the superpotential contains just 3 additional bilinear terms<sup>6</sup>

$$W = W_{\text{MSSM}} + \epsilon_i \hat{L}_i \hat{H}_u \quad (1)$$

They violate lepton number by one unit and therefore necessarily generate Majorana neutrino masses. Corresponding bilinear R-parity violating terms appear in the soft SUSY breaking terms, but strictly speaking these are not independent parameters because of the tadpole conditions<sup>6</sup>.

In this model at tree-level only one neutrino picks up a mass via mixing with the neutralinos. This tree-level mass can be estimated by<sup>7</sup>

$$m_\nu = \frac{M_1 g^2 + M_2 g'^2}{4 \det(\mathcal{M}_{\chi^0})} |\vec{\Lambda}|^2 \quad (2)$$

Here,  $M_1$  and  $M_2$  are the MSSM gaugino masses,  $\mathcal{M}_{\chi^0}$  is the MSSM neutralino mass matrix and  $\vec{\Lambda}$  is defined by  $\Lambda_i = \epsilon_i v_d + \mu \langle \tilde{\nu}_i \rangle$ , with  $\langle \tilde{\nu}_i \rangle$  being scalar neutrino vevs.

Since only one neutrino gains mass at tree-level in BRPV, to study solar and atmospheric neutrino problems at the same time, it is necessary to include 1-loop corrections. Details are given in <sup>4</sup>.

### 3 Numerical results

After including 1-loop corrections the BRPV model produces for nearly all choices of parameters a hierarchical mass spectrum. The largest neutrino mass can then usually be estimated by the tree-level value. This is demonstrated in Fig. 1, where we show  $\Delta m_{atm}^2$  as a function of  $|\vec{\Lambda}|/(\sqrt{M_2}\mu)$ . As the figure shows, correct  $\Delta m_{atm}^2$  can be easily obtained by an appropriate choice of  $|\vec{\Lambda}|$ .

The solar mass scale, on the other hand, is entirely generated at 1-loop order and therefore depends on the model parameters in a complicated way. Fig. 2 shows one example. The parameter  $\epsilon^2/|\vec{\Lambda}|$  is most important for determining the size of the loop corrections, but loops also show a strong dependence on  $\tan\beta$ .

Turning to the discussion on neutrino angles, we note that as long as the 1-loop corrections are not larger than the tree-level contribution, the flavour composition of the 3rd mass eigenstate is approximately given as

$$U_{\alpha 3} \approx \Lambda_{\alpha}/|\Lambda|. \quad (3)$$

Since atmospheric and reactor <sup>8</sup> neutrino data tell us that  $\nu_{\mu} \rightarrow \nu_{\tau}$  oscillations are preferred over  $\nu_{\mu} \rightarrow \nu_e$  oscillations, we conclude that  $\Lambda_e \ll \Lambda_{\mu} \simeq \Lambda_{\tau}$  is required for BRPV to fit the data. This is shown in figs. 3 and 4.

For the solar angle the situation is more complex. As explained in <sup>4</sup> there are two cases to distinguish. With the usual minimal supergravity unification assumptions, ratios of  $\epsilon_i/\epsilon_j$  fix the ratios of  $\Lambda_i/\Lambda_j$ . Since atmospheric (and reactor) neutrino data imply that  $\Lambda_e \ll \Lambda_{\mu}, \Lambda_{\tau}$  only the small angle solution to the solar neutrino problem can be ob-

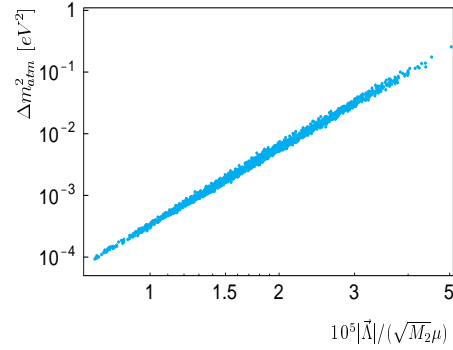


Figure 1. The atmospheric  $\Delta m^2$  as a function of  $|\vec{\Lambda}|/(\sqrt{M_2}\mu)$ . The figure shows how the tree-level approximation can be used to fix the largest mass scale in the bilinear model.

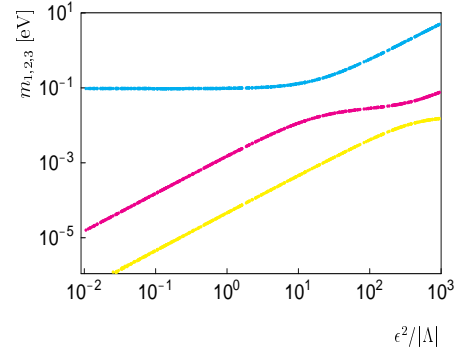


Figure 2. The solar  $\Delta m^2$  as a function of  $\epsilon^2/|\vec{\Lambda}|$  for otherwise fixed parameters of the model. The figure shows how the importance of loop corrections increases with increasing  $\epsilon^2/|\vec{\Lambda}|$ .

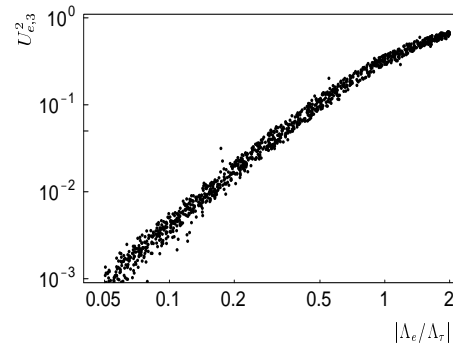


Figure 3.  $U_{e3}^2$  as a function of  $\Lambda_e/\Lambda_{\tau}$ .

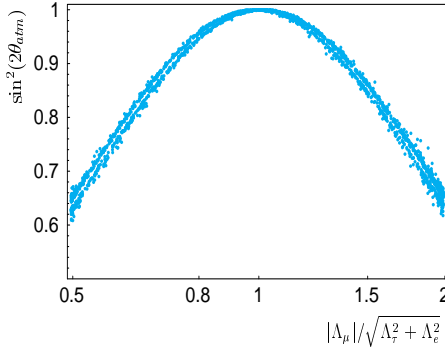


Figure 4. Atmospheric neutrino mixing angle as a function of  $|\Lambda_\mu|/\sqrt{\Lambda_\tau^2 + \Lambda_e^2}$ . Since  $\Lambda_e \ll \Lambda_\mu, \Lambda_\tau$  is required by the reactor neutrino data,  $\Lambda_\mu \simeq \Lambda_\tau$  is needed to obtain large atmospheric neutrino mixing.

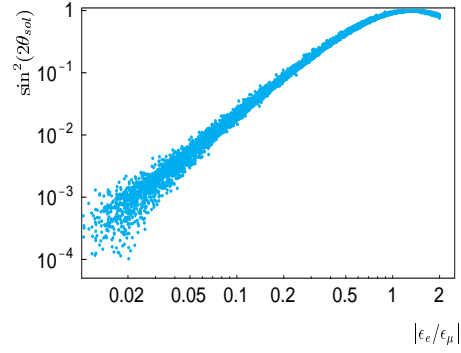


Figure 5. Solar neutrino mixing angle as a function of  $\epsilon_e/\epsilon_\mu$ .

tained in this case. However, even a very tiny deviation from universality of soft parameters at the unification scale relaxes this constraint sufficiently, such that also large angle solar solutions can be obtained in our model, see Fig. 5.

#### 4 Conclusions

Bilinear R-parity violating SUSY, despite being a very simple extension of the MSSM can explain atmospheric and solar neutrino data<sup>4</sup>, once 1-loop corrections are taken carefully into account. The main attractiveness of the model, however, lies in the fact that it can be tested at future accelerators. In<sup>5</sup> we discuss the definite predictions made for neutralino decays.

#### Acknowledgments

This work was supported by DGICYT grants PB98-0693 and SB97-BU0475382 (W. P.), by the TMR contracts ERBFMRX-CT96-0090 and ERBFMBICT983000 (M. H.).

#### References

1. Y. Fukuda *et al.* Phys. Rev. Lett. **81**, 1562 (1998); and hep-ex/9805006
2. N. Fornengo, M. Gonzalez-Garcia & J. Valle, Nucl. Phys. **B580** (2000) 58;

M. Gonzalez-Garcia *et al.*, Nucl. Phys. **B573**, 3 (2000); an updated discussion of neutrino data was presented by M. C. Gonzalez-Garcia at this conference, and is available from <http://neutrinos.uv.es/>.

3. A simple search at <http://xxx.lanl.gov/find/hep-ph> reveals hundreds of attempts to explain neutrino masses in the light of atmospheric and solar data
4. M. Hirsch, M.A. Diaz, W. Porod, J.C. Romao and J.W.F. Valle, hep-ph/0004115, to appear in Phys. Rev. **D**; J.C. Romão, M.A. Diaz, M. Hirsch, W. Porod and J.W.F. Valle, Phys. Rev. **D61**, 071703 (2000)
5. M. Hirsch, W. Porod, J.C. Romao and J.W.F. Valle, talk at this conference
6. M.A. Diaz, J.C. Romao and J.W.F. Valle, Nucl. Phys. **B524** (1998) 60
7. M. Hirsch and J. W. F. Valle, Nucl. Phys. **B557**, 60 (1999); M. Hirsch, J. C. Romao and J. W. F. Valle, Phys. Lett. **B486** (2000) 255
8. M. Apollonio *et al.*, Phys.Lett. **B466** (1999) 415; F. Boehm *et al.*, hep-ex/9912050